Relationships of crop and soil management systems to meteorological variables and potato diseases on a Russet Burbank cultivar

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Abstract

Crop, soil and water management systems may alter microclimatic conditions of agronomic crops and substantially affect plant growth and pest dynamics. However, the extent to which this may impact meteorological variables of potato canopy in a humid temperate region has not been substantially determined. Field plots of Russet Burbank potato were established to assess the potential impacts of different management systems on meteorological variables and subsequent effects on disease dynamics during the cropping cycle. The effects of five cropping systems (*i.e.* Status Quo -SQ, Continuous Potato -PP, Soil Conserving -SC, Disease Suppressive -DS, and Soil Improving -SI) and irrigation application on meteorological variables of potato canopy were investigated from 2006 to 2009. Air and soil temperatures, relative humidity, leaf wetness, and soil water potential were assessed during the potato cropping cycle (May to September). The cropping systems had diverse, but limited significant effects on the meteorological variables of a Russet Burbank potato canopy, implying that treatment effects were similar. It appears that climate induced effects from the environment surrounding field plots substantially negated any cropping system or water treatment effects in field plots. In contrast, data for potato disease development, including early blight, stem canker, black scurf, and common scab, demonstrated consistent significant effects due to management system, indicating that disease parameters were affected by cropping system factors not related to potato canopy microclimate. These results suggest that in a humid environment, selective use of systems management may optimize potato growth and productivity and simultaneously minimize adverse microclimate.

Key words: Cropping systems, Disease effects, Humid temperate region, Meteorological variables, Potato canopy.

1. Introduction

In the Northeastern humid region of the United States, potatoes are often grown under rainfed conditions and occasionally supplemented with irrigation water in the years of deficit rainfall (Dalton *et al.*, 2004). In this region, potato cultivation is characterized by high mechanization and adequate farm inputs

to optimize tuber yield, size and quality primarily for the processing industry as well as utilization for table stocks (Halloran *et al.*, 2013). Although potato production has been a major economic activity in Maine, its sustainability is questionable in comparison to the Northwestern States that have lower production costs and higher yields.

The sustainability of potato production and subsequent benefits derived from it have been the subject of considerable interest and research (He *et al.*, 2012). In that regard, various attempts have been made over the years to quantify the benefits attributed to sustainable methods of potato production as well as the evaluation of production methods to enhance the goals of sustain-

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able potato production. Therefore, crop and soil management systems (cropping systems) and associated production practices have been the subject of various research investigations (Olanya *et al.*, 2006; He *et al.*, 2012). Similarly, the use of water management options or supplemental irrigation to optimize potato production in an otherwise humid environment have also been an important consideration, particularly in cropping years or duration of crop growth where insufficient rainfall are encountered.

The meteorological variables of Russet Burbank potato cultivar and how they are affected by crop and soil management systems may be important in crop production. This is because components of crop management systems, such as rotations, fertility adjustments, water applications, and compost amendments, may invariably influence canopy microclimate, which may in-turn subsequently impact pest abundance and potato productivity (Olanya *et al.*, 2007; Starr *et al.*, 2008). The impacts of water application options on potato as they relate to crop developments have been previously documented, particularly in production regions with marginal precipitation. Similarly, various management strategies can have significant impacts on pest dynamics (Rotem and Palti, 1969).

We established five potato cropping systems with a view of elucidating the long-term effects of such systems on potato sustainability relative to previous production methods commonly used by growers in the northeastern part of the United States, where crop productivity is dominated by potato and 1 or 2 other rotation crops (barley or sweet corn / leafy greens). In this research, the assessment of meteorological variables of a potato canopy, as influenced by potato cropping systems and water management were investigated. The primary objective was to document if systems management in non-contiguous potato plots can substantially influence microclimate during the potato cropping cycle at Presque Isle, Maine, characteristic of the northeast production region of the United States. A secondary objective was to assess if these changes in microclimate were associated with observed cropping system effects on the incidence of foliar and soil-borne potato diseases. Cropping system effects on potato diseases in these field studies were more directly addressed and discussed in previously published papers (Larkin *et al.*, 2011b; Olanya *et al.*, 2009).

2. Materials and Methods

2.1 Field plots, crop and soil management systems

Field plots were established in 2004 as part of long-term cropping systems experiments at the USDA-Agricultural Research Service research site at Presque Isle in northern Maine. The field site consists of a Caribou sandy loam (Fine-loamy, isotic, frigid Typic Haplorthods) soil type and geographically situated at Latitude 46° 41' N, and Longitude 68° 2' W. The experiments consisted of a split-block design with five replicate blocks with irrigation and cropping system as the main and split factors, respectively. Field plots were 15 × 6 m (length × width) with each plot containing four rows. For the irrigation treatment, field plots were either irrigated or not irrigated (rainfed). The crop and soil management (cropping) systems consisted of five treatments that were designed to assess soil and crop management systems to optimize potato productivity. The crop and soil management systems consisted of: 1) Status Quo (SQ), typical 2-yr rotation in northeast US (barley/red clover-potato); 2) Soil Conserving (SC), 3-yr limited tillage grain-forage rotation (barley/timothy-timothy-potato); 3) Soil Improving (SI), same as SC, but with yearly additions of composted dairy manure; 4) Disease Suppressive (DS), 3-yr rotation featuring disease-suppressive crops and practices (Mustard green manure/rapeseed cover crop-Sudangrass green manure/winter rye cover crop-potato); and 5) Continuous Potato (PP) representing a non-rotation control. Details and methodologies involved in the different cropping systems treatments have been previously described (Olanya *et al.*, 2009; He *et al.*, 2010; and Larkin *et al.*, 2011b). The planting and harvest dates, as well as the duration and amount of water applications and rainfall are shown in Table 1.

2.2 Sensors and environmental measurements

Environmental (meteorological) variables were measured with Watchdog data loggers (Model 450; Spectrum Technologies, Plainfield, IL, USA). Leaf wetness was measured with leaf wetness sensors (Model 3666) inserted in the external ports of data loggers, deployed and maintained near the center of the potato canopy in field plots. The leaf wetness sensors were attached to ring stands. Canopy air temperature and relative humidity (RH) were recorded hourly with internal sensors (RH/Temp) within the Watchdog data loggers. Average maximum, average minimum, and

Table 1. Planting and harvest dates, and irrigation water amounts applied to field plots of a Russet Burbank potato cropping systems experiment at Presque Isle, ME.

Year	Planting date	Harvest date	Rainfall amount (cm) ^x	Irrigation amount (cm) ^x
2006	June 1	Oct. 4	47.3	19.1
2007	May 24	Oct. 1	37.3	38.1
2008	May 29	Oct. 1	44.2	25.4
2009	May 1	Sept. 30	45.16	0.0 ^w

^xRefers to total rainfall/irrigation from May to September of each year.

^wNo irrigation events were scheduled in 2009 due to the adequate amount of rainfall in the cropping systems plots.

mean temperatures and RH were determined from the hourly values of each (maximum, minimum, and mean values) recorded during a 24 hr period (daily) and then averaged over the entire season. Rainfall was recorded with a tipping bucket rain gauge, while soil temperature and soil water potential were quantified with soil temperature and soil water mark sensors deployed at 15 cm below the soil surface. Except for the sensors below the soil surface, the heights of environmental sensors above ground were adjusted to maintain positions within the potato canopy. Environmental sensors were maintained in each cropping systems treatment and data outputted at 30-minute intervals.

2.3 Disease assessments

The potato foliar disease early blight, incited by *Alternaria solani*, was assessed in the two inner rows of field plots (4 row plots), in replicated treatments throughout each cropping season. Disease evaluations were based on visual assessments from replicated field plots based on W-shaped sampling techniques. Early blight was assessed four times during the cropping cycle during the tuber bulking period. In 2006, evaluations for early blight incidence were done on August 14, 23, 31, and September 14. In 2007, evaluation dates for early blight were done on August 7, 12, 22, and September 11. In 2008, early blight disease was assessed on August 14, 22, 30, and September 8. Soil-borne diseases, including stem canker and black scurf caused by *Rhizoctonia solani*, and common scab caused by *Streptomyces scabiei* were assessed at harvest on roots and stems (stem canker) and tubers (black scurf and common scab) from representative samples collected from each plot in the field. Details of

the sampling and disease assessment methodologies are provided in Larkin *et al.* (2011b).

2.4 Statistical analysis of experimental data

Meteorological variables were analyzed using analysis of variance (ANOVA). The average values for meteorological variables for a cropping cycle for each year and cropping systems were computed by Proc Means of the statistical analysis system. Microclimatic data consisting of canopy air temperature, RH, soil temperature, soil water potential and leaf wetness were averaged for each hour of the day for the duration of the cropping season for comparison of diurnal patterns and treatment effects on meteorological parameters. The significance of treatment effects (cropping systems and irrigation) were computed by General Linear Models (GLM) of Statistical Analysis System (SAS Institute Inc., Cary, NC). For the early blight, disease values during the first and second assessments were very low or mostly zeros, and therefore analysis could not be conducted in terms of the time frame for meteorological data compiled within the past 7 days (1 week) prior to disease assessment. However, for the third and fourth assessments, no significant correlation coefficients were found between meteorological factors and disease levels. Therefore, the seasonal averages for the meteorological data were presented in this manuscript. Tuber diseases were assessed after harvest and therefore, the direct effects of the timing of meteorological factors on soil-borne diseases were not computed. Graphical comparisons were utilized for showing treatment effects based on diurnal cycles, yearly or seasonal averages.

3. Results

3.1 Meteorological variables (relative humidity (RH), air temperature, soil temperature) of a potato canopy during the cropping cycle and yearly averages

The average maximum RH (%) ranged from 84 ± 2.7 to 98 ± 0.8 % during 2006 to 2008 cropping cycles (Fig. 1A). The average minimum RH in field plots were 43 ± 1.3 % to 49 ± 1.5 %, while mean RH ranged from 82 ± 1.6 % to 90 ± 1.3 % from 2006 to 2009, when data were averaged over the cropping cycle (May 5 to September 15) in each year (Fig. 1A). The average RH values in potato field plots did not vary significantly

($P > 0.05$) among years.

The RH values were consistently high in potato canopy in 2009. The average RH values ranged from 90 ± 4.8 to 100 % when data was averaged from days of the year 125 to 255 during the cropping cycle of 2009 (Fig. 2A). The average RH values varied diurnally during the cropping cycles from 2006 to 2009. The average RH values were highest at night-time and in the early hours of the morning from 2000 to 0600 h and subsequently decreased at day hours (Fig. 3A). The pattern was very similar across all treatments.

In addition, the average maximum, average minimum, and mean air and soil temperatures of a potato canopy during the cropping cycle were similar across

Fig 1. Avergaed maximum, mean and minimum Relative Humidity – RH (A), Air and Soil Temperatures (B) from a Russet Burbank potato cropping systems experiments at Presque Isle, ME from 2006 to 2009.

Fig. 2. Mean RH and canopy air temperature (A) and average soil temperature and rainfall (B) from a Russet Burbank potato experiment (May 5 to Sept 15) at Presque Isle, ME, 2009.

years with the exception of 2009 (Fig. 1B). The mean canopy air temperatures ranged from 9 ± 2.2 °C to 19 ± 2.9 °C in 2009. The average maximum temperatures ranged from 22 ± 0.4 °C to 23 ± 0.4 °C (2006 to 2008) but were 19 ± 0.4 °C in 2009. The mean air temperature was 16 ± 0.4 °C during 2006 to 2008 and was slightly lower (14 ± 0.3 °C) in 2009. From day of year 125 to 255, canopy air temperatures ranged from 9.2 °C to 20.6 °C (Fig. 2A). The mean canopy temperatures were less than 15 °C when day of the year were 125 to 155, while the temperature ranges exceeded 15 °C on day of year 160 to 235 (Fig. 2A). The average canopy air temperature was well below 13 °C at night hours and increased in excess of 18 °C during

the day hours (Fig. 3B).

The mean soil temperatures (16 ± 0.3 °C to 18 ± 0.3 °C) during the cropping cycle (May 5 to September 15) of 2006 to 2008 did not vary significantly ($P > 0.05$). Averaged soil temperature ranged from 8 ± 1.8 °C to 21 ± 0.5 °C during days of the year 125 to 255 (Fig. 2 B). The sinusoidal occurrence of soil temperatures was recorded and the diurnal pattern was similar to that of canopy air temperature for all years of the experiment. The average canopy air temperature was well below 13 °C at night hours and increased in excess of 18 °C during the day hours (Fig. 3B).

Precipitation amounts varied across the years of 2006 to 2009 (Table 1). In general, the 2007 rainfall

was below the long-term average (data not shown). Although precipitation appears to be adequate during the cropping cycle, there were periods of potato growth particularly during late part of July and August during which there was inadequate rainfall with low soil water potential and therefore, irrigation water was applied to field plots. Therefore, daily rainfall amounts also varied across the cropping cycle such as that shown in 2009 (Fig. 2B).

3.2 Cropping systems effects on meteorological variables (relative humidity (RH), canopy air temperature, soil temperature, soil water potential) associated with potato canopy

When data were averaged seasonally from 2006 to 2008 cropping years, relative humidity (%) in the

cropping systems varied with the irrigation treatment. RH (%) values generally ranged from 73.8 to 79.7 % (Table 2). Significant differences ($P<0.05$) in RH values among cropping systems were observed in the irrigated treatment in which the greatest value of RH was recorded in SC and the lowest value in SQ treatment. Differences in RH values among cropping systems were not significant under rainfed treatment.

No significant differences ($P>0.05$) in minimum, maximum and mean canopy air temperatures as well as soil water potential were recorded when comparisons were made among cropping systems under both irrigated and rainfed treatments. Similarly, soil temperature levels were not significantly ($P>0.05$) affected by potato cropping systems (Table 2). The levels of soil

Fig. 3. Diurnal pattern of average RH (A), Air (B) and Soil Temperatures (°C) recorded in a Russet Burbank potato cropping system plots at Presque Isle, ME from 2006 to 2009.

water potential were similar for cropping systems treatments when data were averaged for each month during potato growth (Fig. 4A). Correlation coefficients of soil water potential and early blight disease levels were not statistically significant ($P>0.07$, $r = 0.15$). However, soil water potential (kPa) varied among cropping systems treatments, especially when measurements were taken during a 24 hr period following irrigation or rainfall events. In this case, the diurnal patterns of soil water potential varied among treatments, but fluctuated relatively little within each cropping system treatment in a 24 hr period (Fig. 4B).

A diurnal pattern of leaf wetness duration was recorded from 2006 to 2009 when graphical presentations of leaf wetness data versus hours of the day were made. The season averages of leaf wetness data for 2008 and

2009 showed that leaf wetness hours was relatively greater during the night and early hours of the morning (2100 to 0900 hours) than at day hours during which values substantially decreased (Fig. 5). In both years, average values of ≥ 6 (relative units) during the cropping cycle showing that wetness in potato foliage were relatively similar within a cropping cycle and years (Fig. 5). The cropping systems effects on leaf wetness duration showed similar diurnal patterns and leaf wetness duration were relatively greater during the similar night and early morning hours than at day hours. The sinusoidal effects of leaf wetness durations were also detected among cropping systems in 2006 and 2007 cropping years (data not shown). No irrigation treatments were applied to field plots in 2009.

Fig. 4. Average soil water potential (kPa) during the cropping cycle from June to September, 2008 (A) and diurnal pattern of soil water potential in the cropping systems experiments. The treatments consisted of: DS=disease suppressive, PP= continuous potato, SC=soil conserving, SI=soil improving, and SQ=status quo.

Table 2. Relationship of cropping systems and meteorological factors of a Russet Burbank potato cropping systems experiment at Presque Isle, ME (2006 to 2008).

Microclimatic variable	Cropping systems ^w	Irrigated treatment	Rainfed treatment
Relative Humidity (%)	SC	79.72a ^x	77.31a
	DS	78.67ab	76.64a
	PP	78.61ab	76.78a
	SI	76.09ab	77.47a
	SQ	73.83b	78.11a
Air Temperature (°C)	SC	17.45a	17.51a
	DS	17.40a	17.48a
	PP	17.50a	17.57a
	SI	17.35a	17.56a
	SQ	17.58a	17.51a
Soil Water Potential (kPa) (mean)	SC	-48.62a	-77.96a
	DS	-55.36a	-74.90a
	PP	-56.58a	-63.03a
	SI	-53.90a	-73.83a
	SQ	-52.19a	-73.45a
Soil Water Potential (kPa) (minimum)	SC	-113.02a	-149.97a
	DS	-119.60a	-148.57a
	PP	-124.79a	-132.14a
	SI	-115.88a	-131.07a
	SQ	-117.68a	-147.67a
Soil Temperature (°C)	SC	17.62a	18.20a
	DS	17.59a	17.79a
	PP	17.87a	18.10a
	SI	17.53a	17.70a
	SQ	18.29a	18.06a

^wCropping systems treatments: SC, DS, PP, SI, and SQ refer to soil conserving, disease suppressive, continuous potato, soil improving, and status quo treatments.

^xMeans within columns for each parameter followed by the same letter are not significantly different ($P>0.05$) according to Fisher's LSD test.

No irrigation events were scheduled in 2009 and data for the 2009 cropping systems were not included in this Table.

The average solar radiation during the cropping cycle ($\text{MJ/m}^2/\text{d}$) for days of the year showed wide variations during the cropping cycle. The averaged solar radiation generally ranged from 8 to 26 MJ/m^2 (Fig. 6A). The sinusoidal effects of solar radiation (W/m^2) were recorded during 2006 to 2009 cropping years (Fig. 6B). Differences in total solar flux were not statistically significant ($P>0.05$).

3.3 Cropping systems and irrigation effects on disease levels

For early blight, disease incidence, severity, and pathogen lesions averaged across years were in the range of 17.9 to 50.1 %, 2.4 to 12.4 %, and 8.9 to 25.6 %, respectively. A combined analysis of variance for early blight incidence, disease severity, and pathogen lesions showed high variation in disease levels

Fig. 5. Cumulative leaf wetness duration in potato plots in 2008 and 2009 cropping cycles. Data represents diurnal pattern of leaf wetness duration at various hours of the day and night.

across cropping systems and irrigation treatments. Significant differences ($P < 0.05$) in the incidence, severity and pathogen lesions were detected among cropping systems (Table 3). All cropping systems resulted in lower disease levels than the PP system for all early blight disease parameters, with reductions of 42–64 %, 71–80 %, and 49–65 % for disease incidence, disease severity, and pathogen lesions, respectively

(Table 3). The SI system also reduced early blight incidence by 28 to 38 % relative to the DS and SQ systems. There were significant ($P < 0.05$) effects of water management on disease levels as early blight severity and pathogen lesions were comparatively greater under irrigated than rainfed treatments.

Table 3. The effect of cropping systems and irrigation management on average early blight incidence, disease severity, and pathogen lesions during 2006 to 2008.

Cropping systems ^w	Disease Incidence (%)	Disease Severity (%)	Pathogen Lesions (number)
PP	50.12a ^x	12.39a	25.59a
DS	28.83b	3.54b	12.94b
SQ	24.67b	2.83b	11.13b
SC	22.76bc	2.69b	10.10b
SI	17.85c	2.42b	8.87b
Water management ^x			
Irrigated	33.63a	8.34a	20.79a
Rainfed	30.34a	4.13b	12.35b

^wCropping systems treatments: PP, DS, SQ, SC, and SI, refer to continuous potato, disease suppressive, status quo, soil conserving, and soil improving. Data represents combined analysis of variance for the three years.

^xMeans within columns for each parameter followed by different letters indicate significant differences ($P < 0.05$) according to Fisher's LSD test.

Table 4. The effect of cropping systems and irrigation management on severity of soilborne potato diseases (stem canker, black scurf, and common scab) from 2006 to 2008.

Cropping systems ^w	Stem canker (0–5 scale)	Black scurf (% surface coverage)	Common scab (% surface coverage)
PP	1.57 a ^x	0.85 a	10.59 a
SQ	1.38 b	0.63 b	7.79 bc
SI	1.34 b	0.80 a	8.91 b
SC	1.38 b	0.65 b	7.33 c
DS	1.29 b	0.45 c	6.68 c
Water management			
Irrigated	1.43 a	0.74 a	9.29 a
Rainfed	1.36 a	0.62 b	7.23 b

^wCropping systems treatments: PP, SQ, SI, SC, and DS refer to continuous potato, status quo, soil improving, soil conserving, and disease suppressive treatments. Data represents combined analysis of variance for the three years.

^xMeans within columns for each parameter followed by different letters indicate significant differences ($P < 0.05$) according to Fisher's LSD test.

For soilborne diseases, stem canker severity was lower in all cropping systems relative to continuous potato throughout the study, but was not significantly affected by irrigation (Table 4). Regarding the tuber diseases, black scurf severity was lower in the DS system than all other systems (reduction of 47 % relative to PP), and was also reduced in the SC and SQ systems relative to PP throughout the study (Table 4).

Common scab was also significantly affected by management system, with all rotations resulting in lower scab severity than continuous potato, and lowest levels observed in the SC and DS systems (with reductions of 31–37 %). Both black scurf and common scab severity were lower under rainfed management than irrigated water management systems (average reductions of 16 and 22 %, respectively).

Fig. 6. Mean solar radiation (MJ/m²/d) from a Russet Burbank potato field in cropping systems experiments (May 5 to Sept 15) at Presque Isle, ME, 2008 (A). The standard error bars refer to variation in solar radiation intensity within day of the year measured. The diurnal pattern of average solar radiation (W/m²) was recorded at various day and night hours in potato fields (B).

4. Discussion

Meteorological variables such as relative humidity, air temperature, soil temperature, and soil water potential recorded within the potato canopy varied during the cropping cycles and years and were numerically greater in some cropping cycles and years, but had similar patterns within a cropping cycle and across years. This suggests that seasonal averages of relative

humidity, canopy temperatures, and soil temperatures did not differ significantly. Previous research (Waggoner, 1965) indicated that spatial variation in canopy temperatures and relative humidity at the leaf surface are dependent on the leaf position and architecture which in turn is a function of transpiration (stomata openings) and ventilation at the surface of leaves or canopy. In this research, we did not quantify differences in spatial variation of canopy temperatures and

humidity at the surface of potato foliage. The higher relative humidity during night hours may also be attributed to the presence of soil amendments that lowered night temperatures and increased humidity values conversely. The increased relative humidity at night hours may also be due to greater dew formation.

Cropping systems had different effects on meteorological conditions of the potato canopy. Significant differences in RH values were recorded in treatments under irrigation treatment, implying that crop management options can influence humidity levels of potato canopy under certain conditions such as in this case where humidity conditions were significantly ($P<0.05$) greater in SC and comparatively lowest in SQ treatment. However, average minimum, maximum and mean canopy air temperatures and average soil temperatures were not significantly impacted by cropping systems, implying that crop management had little effect on those parameters.

Previous research (Olanya *et al.*, 2007), demonstrated that irrigation treatments substantially impacted canopy microclimate. In that research, it was documented that surface drip irrigation and sprinkler irrigation altered the canopy microclimate (RH and leaf wetness duration) of a Russet Burbank potato cultivar as opposed to other water management treatments. In related research, it was documented that irrigation treatments could significantly ($P<0.05$) alter soil water balance and available soil water for potato production and yield (Starr *et al.*, 2008) and disease development on various cultivars (Olanya *et al.*, 2010). The above findings differ from the current study in that the duration, amount, and time of water applications were much greater in that research than in the current study. The soil characteristics of the site for the cited research also differ from that of the current study.

Leaf wetness duration has been shown to be a significant component of microclimate of diverse agronomic crops (Rotem and Palti, 1969). For example, wetness of foliage and the duration of that wetness is crucial for colonization or infection of foliage by plant pathogens, saprophytes, or other microbial agents. In this study, leaf wetness duration was not significantly impacted by cropping systems although variations in leaf wetness durations were detected among cropping systems during night time and early hours of the morning. In other related studies, it has been shown that leaf wetness in crop canopy increased as leaf area index (LAI)

increased in the crop (Cappaert and Powelson, 1990). In other studies, increases in relative humidity, leaf wetness, and reduction in canopy temperatures were attributed to plant density and greater leaf area index (Crandell *et al.*, 1971). In our study, although leaf area index were quantified in the potato canopy, no correlation coefficients between leaf area index and leaf wetness duration were determined.

Although the different soil and crop management systems did not have a major impact on potato canopy microclimate, cropping systems had major effects on potato diseases. For the early blight disease, observed effects were as expected. It was expected that continuous potato (PP) system would lead to increases in disease levels in potato fields due to the build-up of higher pathogen populations, lower organic matter, and lower soil microbial activity and diversity. Data averaged across 3 years of the experiment showed that PP had consistently higher disease levels compared to all other cropping systems. The SI system, which includes a 3-yr rotation and yearly additions of compost, generally resulted in the lowest early blight levels among the systems, and this may have been related to increased microbial competition and less favorable conditions for pathogen growth and survival due to the addition of compost. Additional information and analyses on the effects of these cropping systems on early blight disease has been previously published (Olanya *et al.*, 2009).

For the soil-borne diseases, cropping system had a major impact, with most rotations reducing disease severity relative to no rotation (PP), and the DS system generally providing the lowest disease levels of all systems. This is consistent with recent studies that have shown significant reductions in soilborne potato diseases based on cropping system and the incorporation of disease-suppressive crops (Larkin and Griffin, 2007; Larkin *et al.*, 2010; 2011a). Additional information and analyses for cropping system effects on soilborne diseases and soil microbiology has been previously published (Larkin *et al.*, 2011b). Because cropping system effects on diseases were greater and much different than effects on microclimate, this indicates that the disease effects are due to cropping system factors that are not related to meteorological or microclimate effects. For example, the disease-suppressive crops used in the DS system are known to reduce soilborne diseases through multiple mecha-

nisms, including soil biofumigation and alterations in soil microbial community characteristics (Larkin *et al.*, 2011a; 2011b). In addition, longer rotation periods and inclusion of greater crop biomass and residues are expected to reduce disease relative to no rotation. In this way, systems designed for improving potato production may simultaneously be used to impede development of pathogens or potato diseases as well. Therefore, care must be taken in developing cropping systems that can both optimize potato production and minimize disease/pest development.

5. Conclusion

We conclude that the seasonal averages of meteorological variables of a Russet Burbank potato canopy were not significantly impacted by crop management systems and water applications during the cropping cycle (May to September) in a four year study. Diurnal and sinusoidal patterns of microclimatic parameters recorded showed temporal differences during the night hours. It appears that treatment induced effects (cropping systems and irrigation) were negated by the climatic patterns of the environment surrounding field plots. In contrast to that, we observed significant cropping systems effects on foliar and soil-borne diseases which do not appear to be related to microclimatic parameters at the canopy level. In the case of early blight, the pathogen can survive and initiate infection under diverse temperature and moisture regimes such as that encountered in the experiments. For the soil-borne pathogens, our data showed that disease suppressive crops, soil water potential, and soil microbial activities were greater factors in pathogen survival and disease dynamics than the microclimate. Selective use of management systems may be used to optimize potato growth and yield and minimize microclimate and disease effects.

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